Ministry of
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Communications

Ontario

MI-65

INVESTIGATION OF CONCRETE SEGMENT NO. 254SB CONTRACT 80-44 HWY. 406

MATERIALS INFORMATION
ENGINEERING MATERIALS OFFICE

INVESTIGATION OF CONCRETE

SEGMENT NO. 254SB

CONTRACT 80-44 HWY. 406

by
G. P. Wilson
Senior Concrete Engineer
Concrete Section
Engineering Materials Office
Highway Engineering Division

Ontario
Ministry of Transportation
and Communications

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1. ABSTRACT

Concrete cores from a segment of the Twelve Mile creek structures, Hwy.406, were tested in the laboratory to evaluate the properties of 41.4 MPa class, commercially produced, concrete for Cont.80-44.

Testing of 100 mm diameter cores, from all parts of segment No.254SB, 21 months after completion of construction, indicated that the concrete then had a mean compressive strength of 67 MPa and a standard deviation of 5.78 MPa.

The mean concrete density was 2387 kg/m^3 with a standard deviation of 18 kg/m^3.

Modulus of elasticity testing was performed on 36 100 mm diameter concrete cores. The mean modulus of elasticity was 33.8 GN/m^2, with a standard deviation of 2.11 GN/m^2.

The resistance of the concrete in the segment to the scaling of deicing chemicals, was well within the MTC requirements for concrete durability as measured by the salt scaling test.

The physical dimensions of the segment were measured and were found to agree with the plan dimensions. The drape of some longitudinal cable ducts did not appear to be a smooth catinery.

No corrosion of rebars, ducts or stressing cables was observed, but after compression testing concrete segregation was observed in one core.

2. OBJECTIVE

The objective of the field investigation, laboratory testing and observations, was to determine the characteristics of the 41.4 MPa concrete cast in segment No. 254SB. The testing included:

- Scaling Resistance to Deicing Chemicals
- Modulus of Elasticity
- Compressive Strength
- Density

3. INTRODUCTION

The use of prestressed concrete segmental construction to build long span structures over difficult terrain is becoming more frequent. The first, MTC designed precast, segmental concrete box girder bridges for Twelve Mile creek in St. Catherines, Ontario were completed in May 1982. The two structures were constructed by the balanced cantilever method. The southbound structure is 398 m long, and the northbound structure is 182 m long. Parts of both bridges are on a 500 m horizontal curve. In addition the southbound bridge is on a spiral, a tangent, and a reverse spiral. The bridges are on a 0.5% grade, and they were designed to AASHTO HS 20-44 loading.

The southbound bridge consists of six continuous spans of 47, 76, 76, 76, 76, and 47 m. It consists of 162 precast and 6 cast in place segments. All segments have a constant depth of 2.82 m. The standard segment bottom slab thickness is 229 mm and the web thickness is 457 mm. Due to the high shear strengths produced by the dead loads, a draped tendon layout was employed for all permanent cantilever cables. The top slabs of the segments were transversely post-tensioned. The transverse segment ribs were also post tensioned. The face of each segment was fitted with multiple, non-reinforced, shear keys.

In May 1980 Cont. 80-44 for the two Twelve Mile Creek bridges Site No. 18-233 A and B was awarded to the Kilmer Van Nostrand Company Limited of Toronto. Their low bid was $10.9 million.

The contractor erected an all weather segment assembly and casting building, upstream from the bridge site. Alignment of the match cast segments was controlled from a survey tower. The reinforcing steel cages and cable ducts were assembled for each segment. These cages were lifted into the formwork by a mobile crane. The 41.4 MPa class concrete was supplied by a local ready-mix company. The casting of the concrete in each segment required approximately 2.5 hours. On completion each segment had a mass of approximately 65 tonnes. The casting plant produced segments at the rate of 1.5 per day.

The collapse of a 220 ton crane boom in the segment storage yard reported by O.E. Ramakko at the "International Conference on Short and Medium Span Bridges, Toronto 1982",[1] resulted in damage to, and the recasting of, several segments.

This segment, No. 254SB, now reported upon, was made available for concrete testing during 1982, because it was one of the rejected, crane damaged segments.

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4. Regression Analysis Data.

4. Evaluation of Segment No. 254SB

The purpose of the test program is established in the objectives.

Test Methods

The following are the properties of the segment concrete examined and the test methods used:

A)	Scaling Resistance to Deicing Chemicals	MTC Procedure
B)	Static Modulus of Elasticity of Concrete in Compression	C469-81 Modified by MTC Procedure
C)	Test for Compressive Strength of Cylindrical Concrete Specimens	C39-72
D)	Test for Specific Gravity of Concrete	C642-75

4A. Scaling Resistance to Deicing Chemicals

Four 300 mm diameter by 229 mm deep cores, were diamond drilled from segment No. 254SB, to determine the scaling resistance of the concrete to deicing chemicals. Two of the four cores, numbered 82 and 85 were drilled from Section E-F of the segment, of the remainder, one core was drilled from Section A-B and one from Section C-D of the segment. See Fig. 3. Each core was fitted with a water retaining dyke to its upper perimeter.

The four cores to be subject to salt scaling were moist cured for 14 days, and for a further 14 days in the laboratory. They were then tested in accordance with the requirements of ASTM C672-76, with the following exceptions. The deicer was a three percent sodium chloride solution. The scaling was evaluated after every five cycles by determining the dry mass of the scaled material per unit area of the surface exposed to scaling (kg/m^2). Each core was submitted to one freezing and thawing cycle per day for fifty cycles. The scaling resistance of the cores to deicing chemicals was evaluated by determining the accumulated dry mass of the scaled material, from each core. Fig. 7 shows the range of the test results. Fig. 8 shows the appearance of cores numbered 29 and 82 before and after completion of the fifty freeze thaw testing cycles. The Ministry guideline for concrete acceptance is a maximum cumulative surface loss of 0.8 kg/m^2. The test concrete loss averaged 0.28 kg/m^2 with a maximum surface loss of 0.42 kg/m^2. The test results from the concrete of all four cores are essentially equal, and they are well within MTC performance criteria for durable concrete.

4B, C, and D. Modulus of Elasticity, Compressive Strength Density Testing and Discussion

95 100mm diameter concrete cores were diamond drilled by a contractor from segment No. 254SB during Nov. 1982. Many of these cores contained reinforcing steel, steel cable ducts, and stressing strand. All cores were quickly shipped to the Downsview concrete laboratory. On receipt, all cores were measured, catalogued and photographed. The cores were then stored until July 1983. Before testing commenced, all cores were placed in a lime solution bath for a minimum of 48 hours.

The equipment necessary to carry out the modulus of elasticity testing, in accordance with the requirements of ASTM C469-81, was not available in 1983. A decision was made to carry out the required testing using electrical strain gauges.

50 mm and 100 mm long electrical strain gauges were tested to determine their cost/effectiveness in determining the static modulus and ultimate compressive strength of the concrete cores. Core No. 59A was used for this purpose. The core was fitted with both a 50 mm and with a 100 mm long electrical strain gauge, placed on opposite sides. See Fig. 9. Similar modulus of elasticity results were obtained with both strain gauge lengths, twin 50 mm strain gauges were therefore selected for the testing. When the core was tested within the elastic range of the concrete test measurement, differences in the modulus of elasticity results were noted, when the test was repeated at progressively longer periods of time after the core had been removed from the lime bath, and also when the core was rotated at 90° for the second series of tests.

A decision was made to test a total of 36 100 mm diameter cores from segment No. 254SB to determine the elastic modulus of the concrete. The 36 cores consisted of 6 cores from each of the 6 locations A-B, B-C, C-D, B-E, C-F and E-F which make up the segment. A further decision was made to standardize the time to remove the core from the lime bath, to the performing of the testing, allowing the concrete to surface dry, and the time taken to epoxy the twin 50 mm electrical strain gauges vertically, at 180° around the core (See Fig. 9). This standardized time was 72 ± 3 hours.

The electrical resistance strain gauges were manufactured by Micromeasurements Ltd., Catalogue No. EA-06-20 CBW-120

During the testing, each core was loaded to 40^{t}, and offloaded. This process was repeated 3 times, and X-Y stress strain graphs were obtained during each loading. Each core was then rotated 90°, and the on off loading to 40^{t} was repeated a further 3 times, except that on the 6th loading, the core was tested to destruction. Readings 2, 3, 4 and 5 were averaged to determine the modulus of elasticity of the concrete in the core. The data obtained is shown in Tables 3 and 4.

The results of the testing for each of the 6 segment locations and for the whole segment were analysed statistically and by regression analysis. This statistical data is shown in Tables 3 and 4.

4E. Regression Analyses

The compressive strength, density, and L/D ratios are tabulated in Table 2.

The modulus of elasticity data is tabulated in Table 3.

The compressive strength versus modulus of elasticity data is shown graphically in Fig.12 and the compressive strength data versus density data in Fig.13.

Correlations were tested for compressive strength versus modulus of elasticity, and for compressive strength versus density. For both correlations linear regression was used on 6 sets of data representing the various locations in the segment, taken separately, and again representing all the data on a global basis. In each case the least square line was drawn, and the correlation coefficient was calculated. See Table 4.

1) Compressive Strength versus Modulus of Elasticity:-

The correlation coefficients indicate that there is a definate correlation between the compressive strength and modulus of elasticity data in the case of the global data, and in the sets representing locations B-E and C-F. However, in the concrete cores representing locations A-B, B-C, C-D and E-F the correlation coefficient "r" factors, shown in Table 4A, are not high enough to indicate a correlation, and in some cases the coefficient indicate that the distribution of the data is almost random.

2) Compressive Strength versus Density:-

The correlation coefficient "r" factors, shown in Table 4B, indicate that there is a definate correlation between the compressive strength and concrete density data in the case of the global data and the set representing location E-F. However, in the concrete cores representing locations A-B, B-C, C-D, B-E and C-F the coefficients are not high enough to indicate any correlation.

After the above testing was completed, the broken particles of concrete from each test where collected for density determinations. The density data is shown in Table 2.

4F. Statistical Analysis

A search of the contract records produced concrete construction reports for 182 of the 41.4 MPa class concrete segments. Concrete cylinders were cast by the contractor, K.V.N. at the especially erected all weather segment assembly and casting building sited on the contract.

The typical segment contained 22 m^3 of concrete.

The statistical mean concrete strength of the 182 segments tested in compression was 49.59 MPa, with a standard deviation of 3.12 MPa.

The specified air content of the 41.4 MPa class concrete in the segments from which the two Twelve Mile Creek structures were constructed, was changed twice during their construction. At first the specified air content was 6% ± 1%. This specification was soon changed to 4% ± 1%. Finally the specified air content was required to be 5% ± 1%. A statistical analysis of the actual air contents in the 182 segments tested indicates that the actual mean air content supplied was 4.64%, with a standard deviation of 0.41%.

The mean concrete slump specified was 60 mm ± 20 mm, and that achieved was 75 mm, with a standard deviation of 7 mm.

The mean concrete temperature on delivery to the construction site was 24.4°C, with a standard deviation of 2.7°C.

OBSERVATIONS

MEASUREMENT OF SEGMENT DIMENSIONS

Before the field coring of segment No. 254SB was commenced, the as built physical dimensions of the segment were compared with the measurements required by the drawings for that segment.

All measurements obtained from segment No. 254SB agreed within the specified tolerance with the planned dimensions for that segment.

The excellent correlation between the planned and as built field dimensions and the high degree of dimensional accuracy to which the segment was built had been anticipated, because during construction each segment was carefully inspected for dimensional accuracy, by the MTC contract survey crew, as soon as possible after concrete casting, before that segment was accepted at the contractor's site and before match casting the next segment commenced.

Concrete Segregation

Core number 66B was obtained from wall C-F. This was the only core to exhibit concrete segregation.

During the casting of each segment, the concrete in the walls was very heavily vibrated to ensure that adequate compaction was achieved around the heavy concentration of cable ducts and reinforcing bars in each wall. The concrete in the base and top slabs was then placed.

The segregation in core 66B appears to be due to the heavy vibration. This caused the coarse aggregate to settle, and it may have produced minor localized laitence, but the air content of the hardened concrete appears to be satisfactory.

The use of a superplasticizer to improve concrete flowability and to reduce the possibility of segregation might be appropriate in future similar work.

CONCLUSIONS

The results of the testing and evaluation described in this paper lead to the following conclusions:

i) The concrete cast in segment No. 254SB complied with the requirements of the strength specification for 41.4 MPa class concrete. Concrete production and control was excellent.

ii) The scaling resistance to deicing chemicals of the concrete was well within the generally recognized performance criteria for durable concrete.

iii) The 41.4 MPa class concrete produced by the mix design used on contract 80-44, exhibits very high early compressive strength gain and extra ordinary long term strength gain.

iv) The testing of 36 cores from the segment in compression and for modulus of elasticity is statistically valid, but testing 6 cores from each of the 6 locations in the segment does not provide sufficient data to draw conclusions regarding the distribution of their properties.

v) The production of concrete by a ready mix operation, with a compressive strength of over 20 MPa at 24 hours is possible with the active co-operation of all concerned.

RECOMMENDATION

This report recommends that:

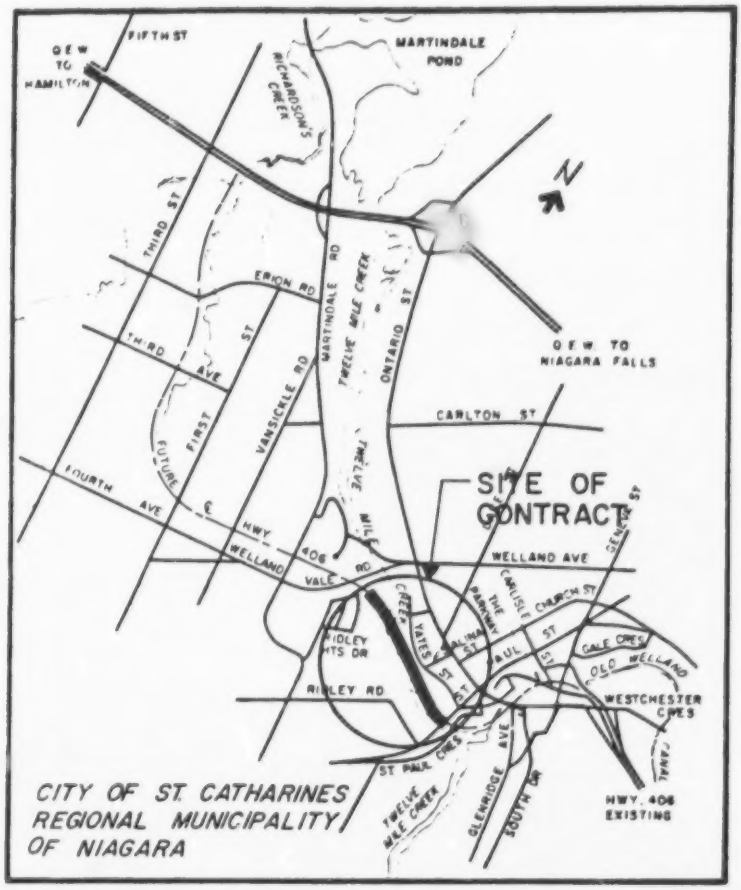
i) Similar future concrete segment testing be designed to be statistically valid, therefore more concrete coring would be required.

REFERENCE

i) Rammakko, O. E., "The Twelve Mile Creek Bridges - Design and Construction", Procedings, International Conference on Short and Medium Span Bridges, Toronto, 1982, Vol. 1, Session 3.

FIGURE 1

SITE OF CONTRACT



Key Plan

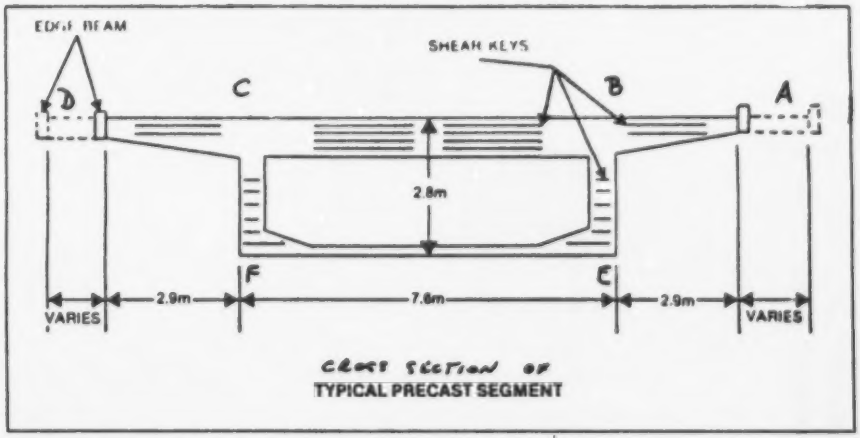
Scale

2000' 0 2000'

FIGURE 2

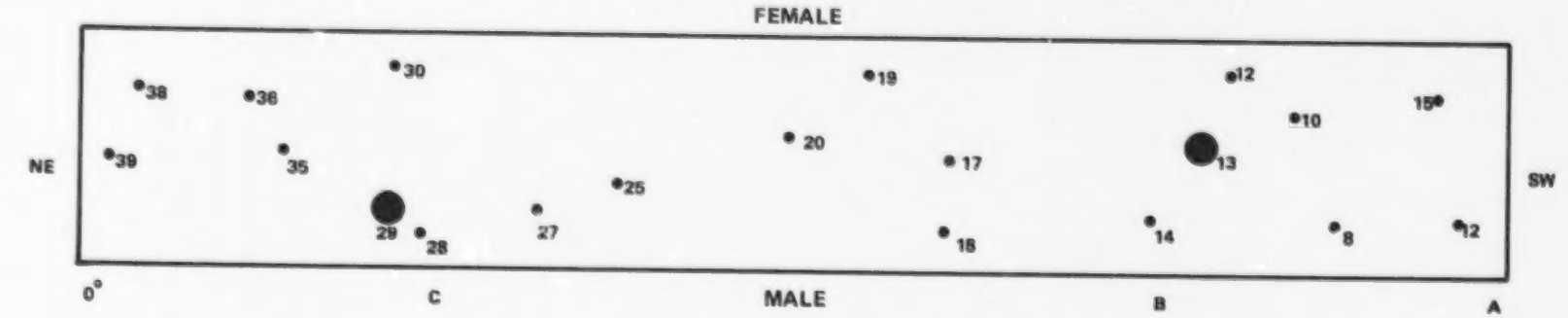
CROSS SECTION OF

TYPICAL PRECAST SEGMENT

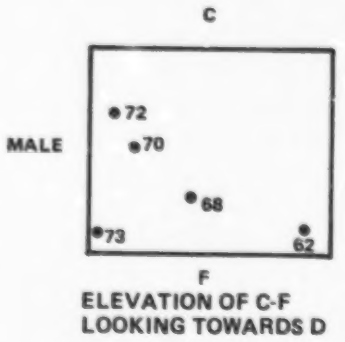


CROSS SECTION OF
TYPICAL PRECAST SEGMENT

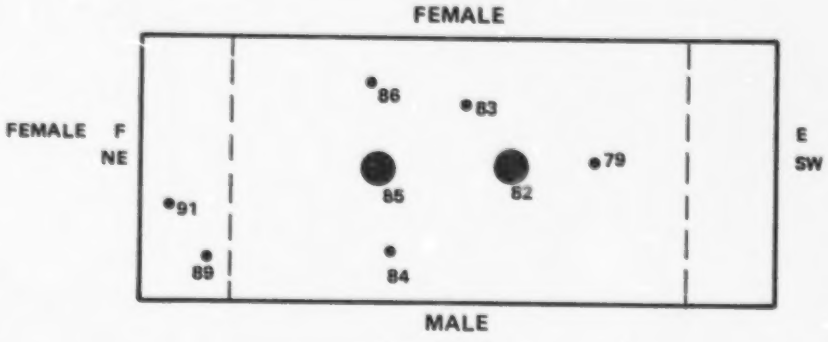
FIGURE 3
LOCATION OF CORES



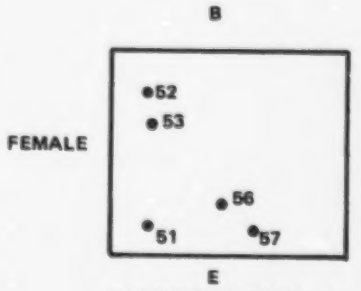
PLAN OF SEGMENT 254 S.B.
SHOWING CORE LOCATIONS



ELEVATION OF C-F
LOOKING TOWARDS D

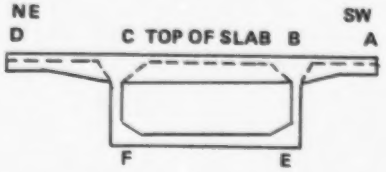


PLAN OF E – F
PLAN OF BOTTOM SLAB



ELEVATION OF B–E
LOOKING TOWARDS A

SCALE 1:96



SKETCH OF CROSS SECTION OF
SEGMENT – NOT TO SCALE

KEY
• 100 mm DIA. CORE LOCATIONS
● 300 mm DIA. CORE LOCATIONS

LOCATIONS OF 100 mm NAD 300 mm DIAMETER CORE HOLES AT SEGMENT No. 254S.B. CONTRACT 80–44

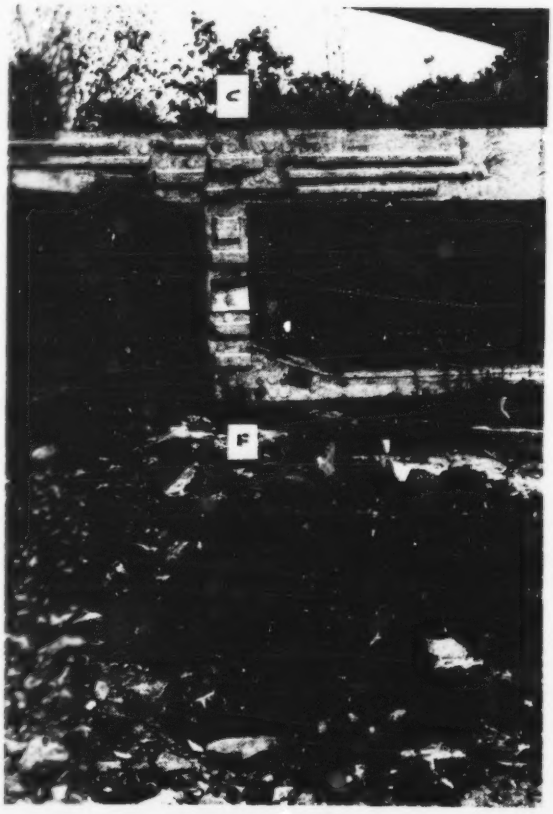


FIGURE 4
LOCATION OF ABANDONED
SEGMENT No 254 S.B.
BEFORE CORING.

FIGURE 5
TYPICAL 100mm DIAMETER CORES
FROM SEGMENT No 254 S.B.

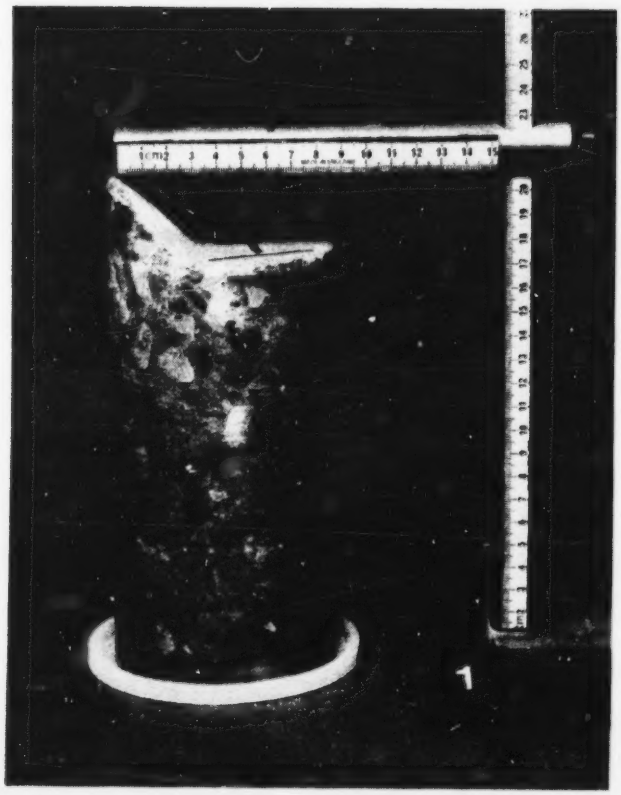


FIGURE 6
IDENTIFICATION OF CORES

● TEST SLAB 1 CORE No. 13 LOCATION A-B

○ TEST SLAB 2 CORE No.29 LOCATION C-D

△ TEST SLAB 3 CORE No. 82 LOCATION E-F

▽ TEST SLAB 4 CORE No. 85 LOCATION E-F

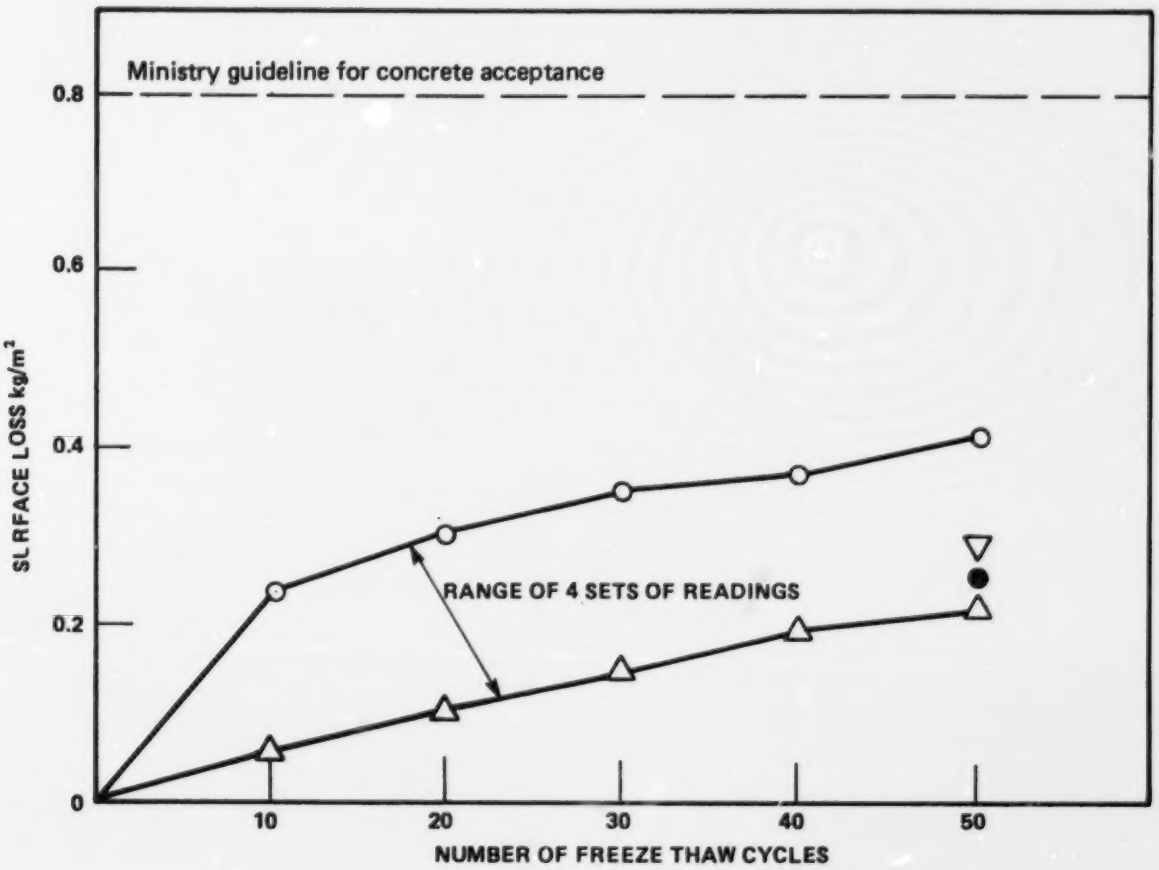
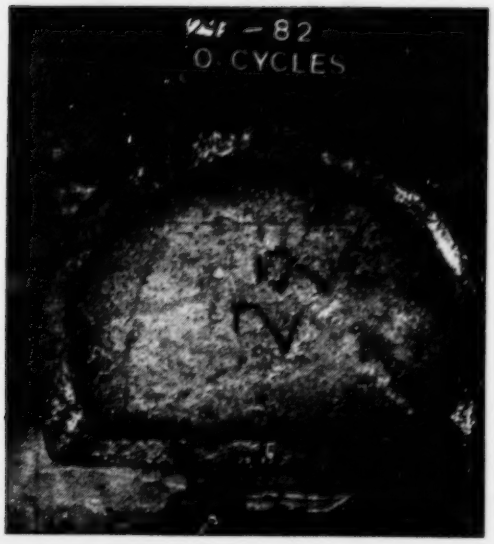
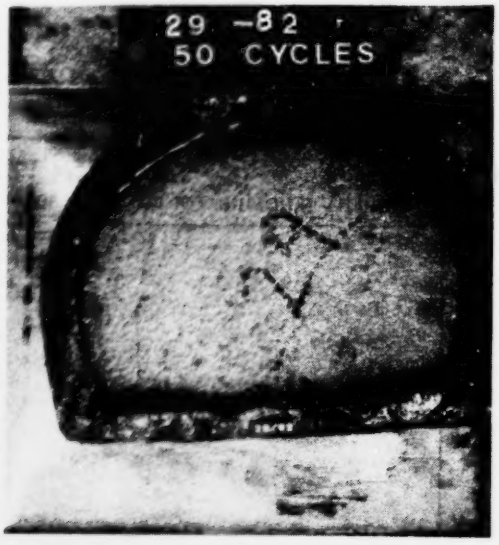


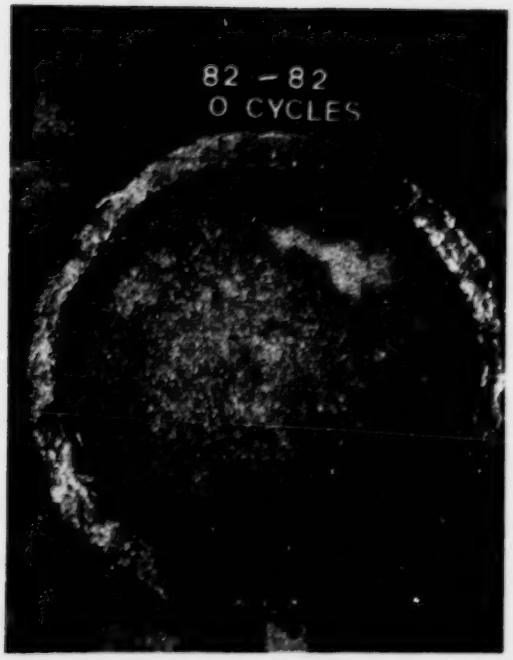
Figure 7

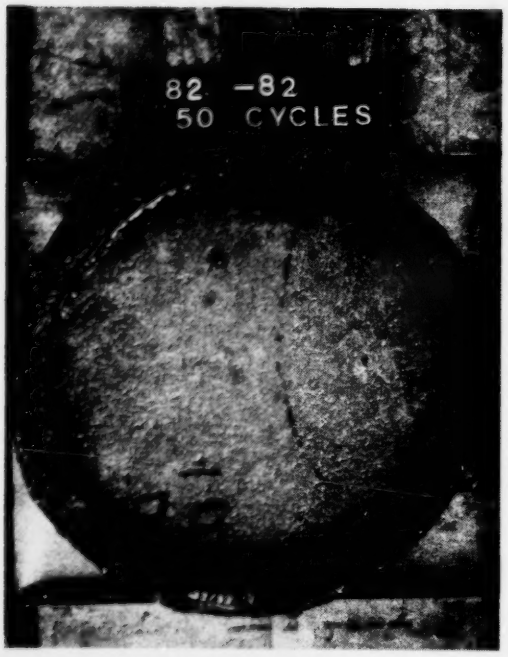
FIGURE 8

APPEARANCE OF SALT SCALING TEST SLABS
BEFORE AND AFTER EXPOSURE TO 50 FREEZE THAW CYCLES,
41.4 MPa CLASS CONCRETE









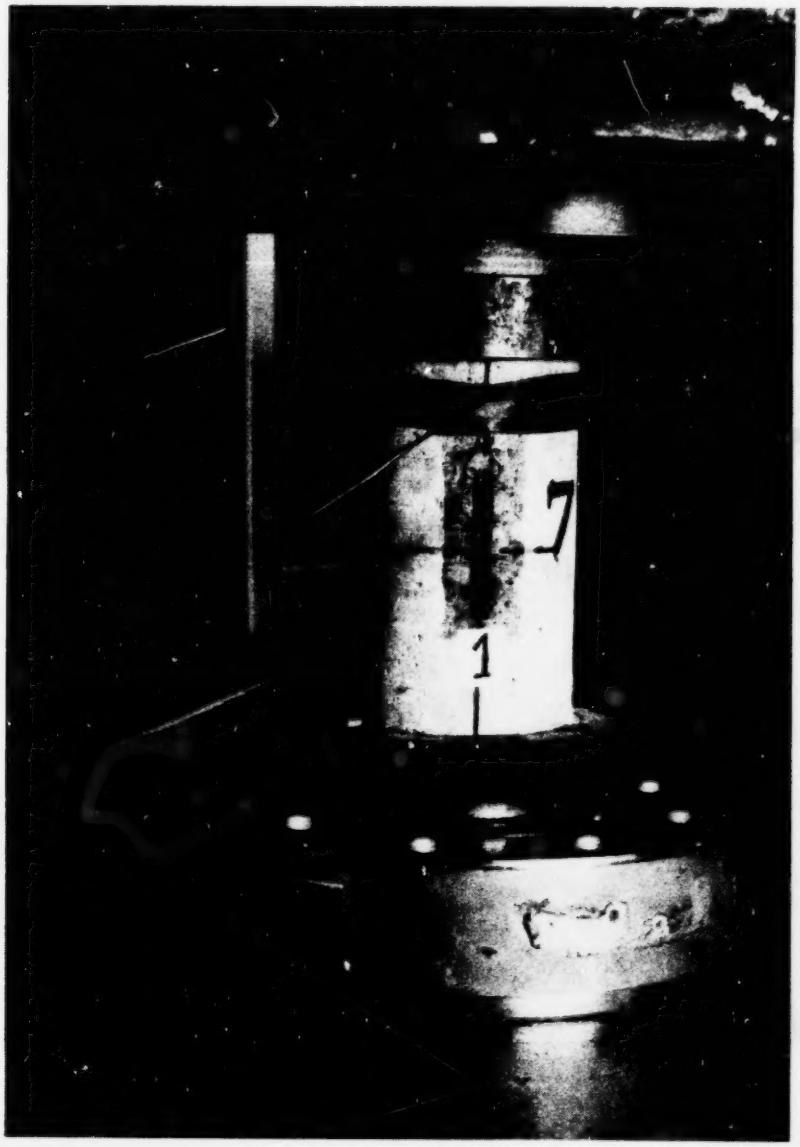


FIGURE 9

ELECTRICAL STRAIN GAUGE TESTING

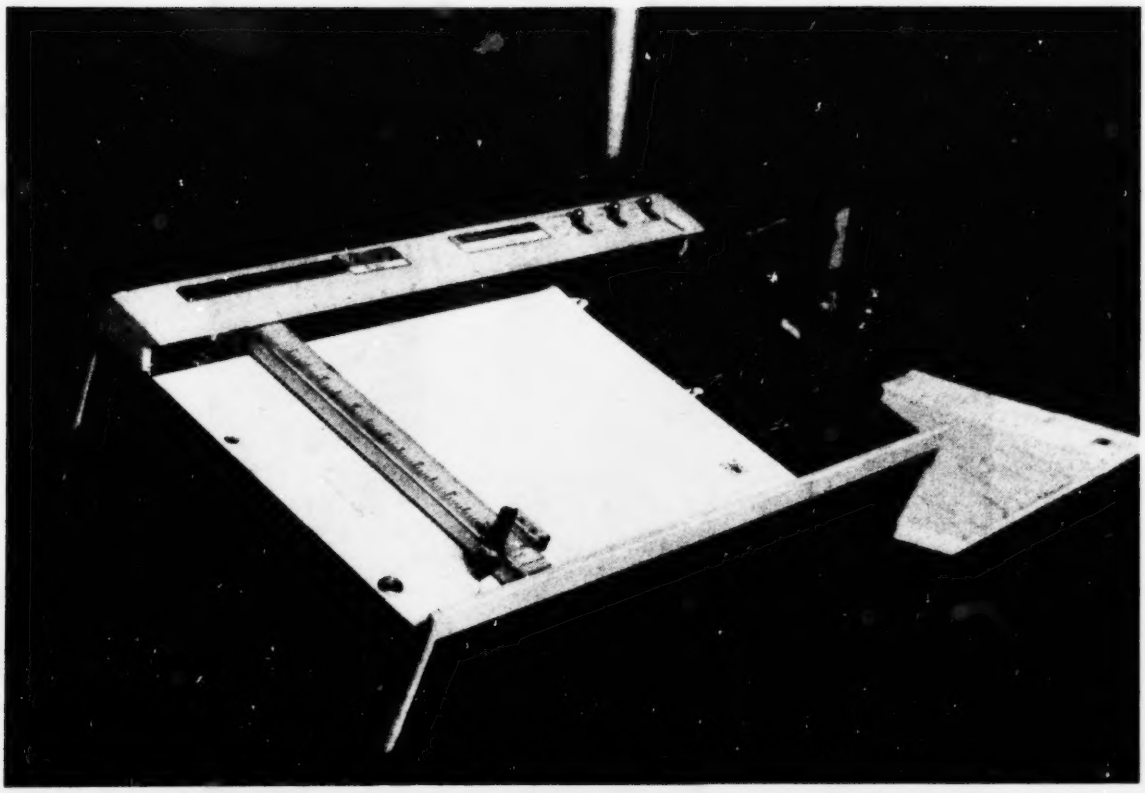


FIGURE 10

X-Y PLOTTER - H.P. 7035B AND H.P. 6101A.

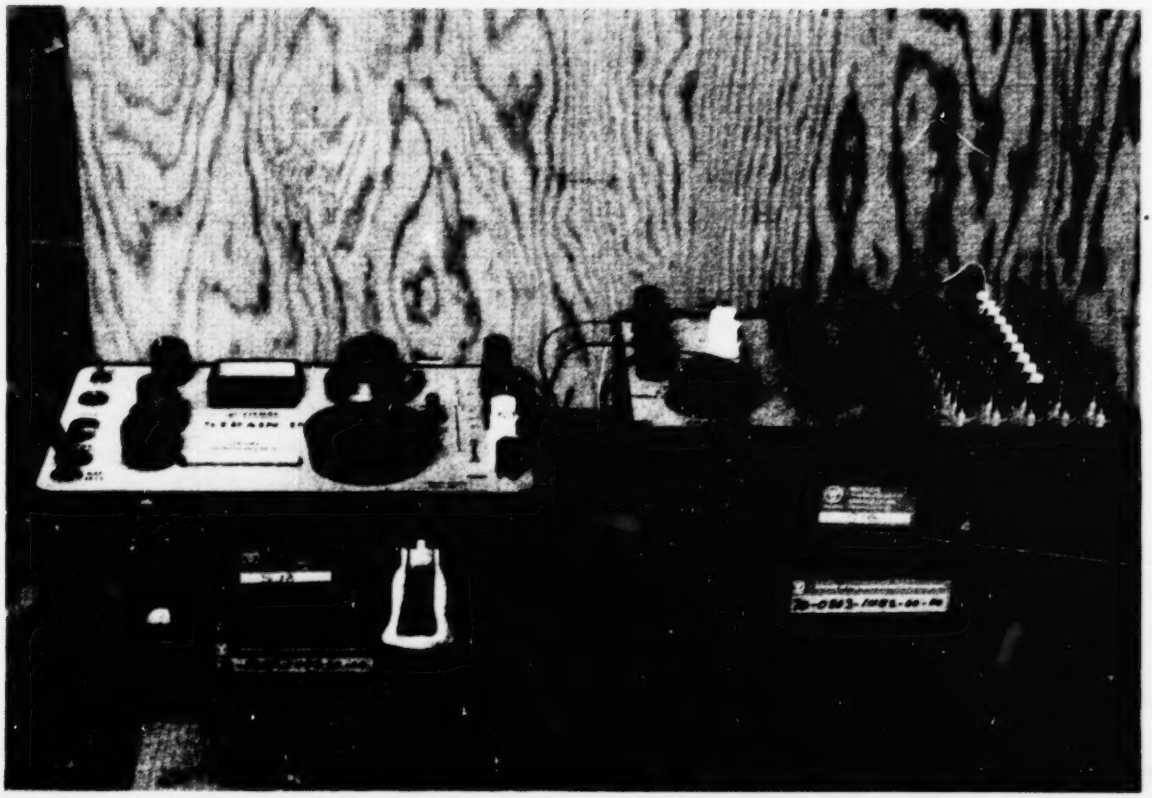


FIGURE 11

VISHAY STRAIN METER

SWITCH AND BALANCE UNITS

FIGURE 12 - COMPRESSIVE STRENGTH
MODULUS OF ELASTICITY RELATIONSHIP

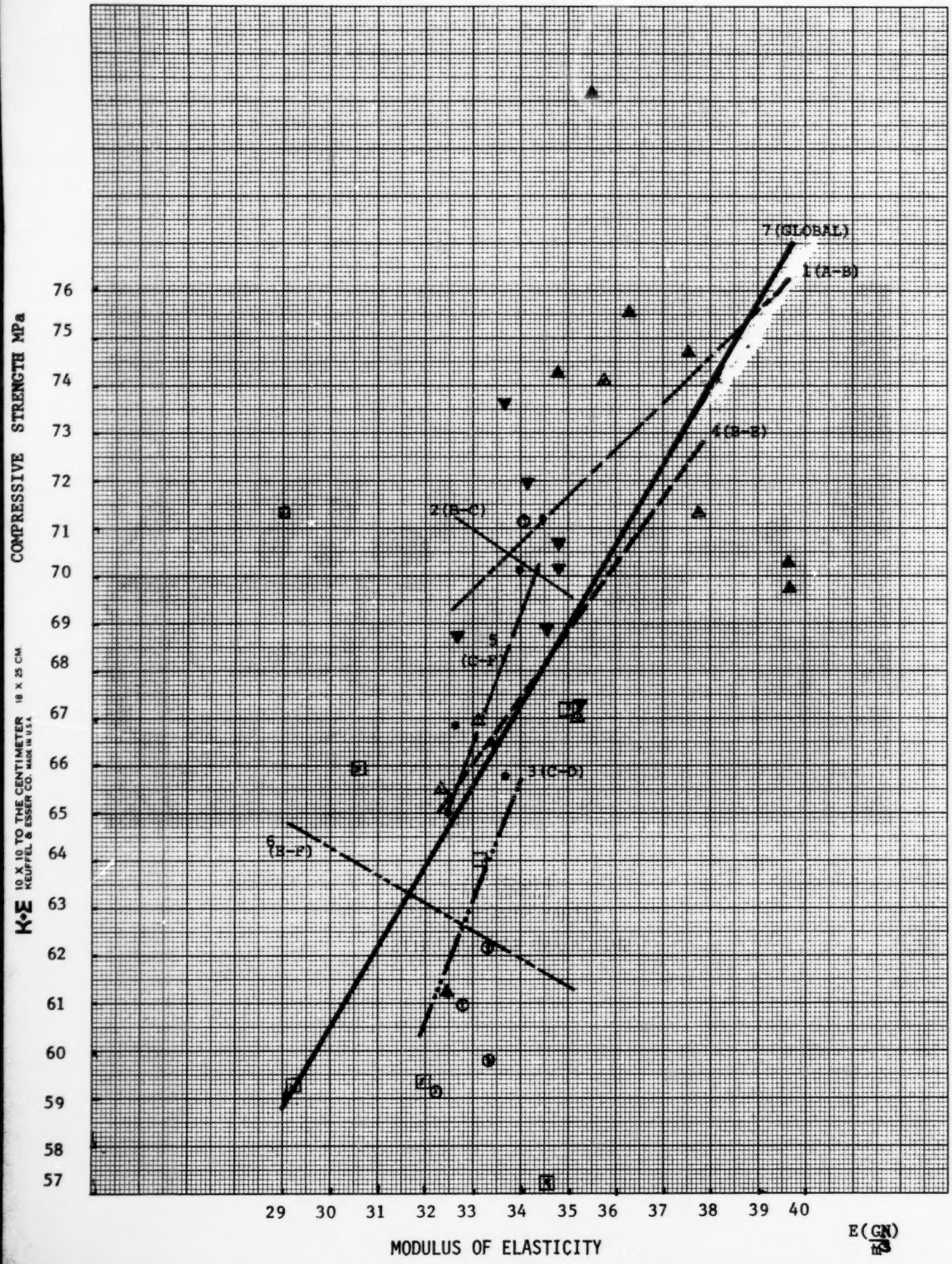
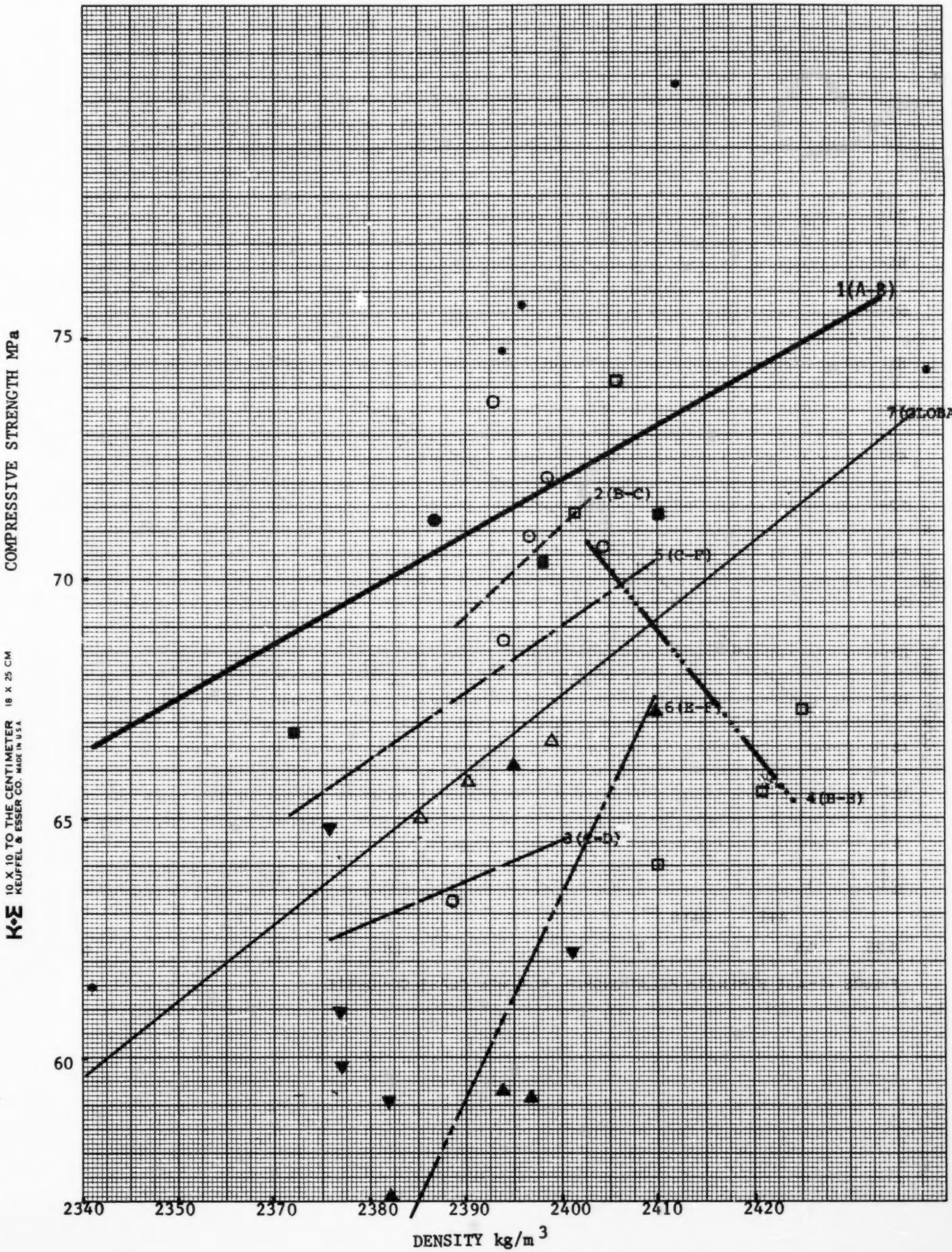


FIGURE 13 - COMPRESSIVE STRENGTH
DENSITY RELATIONSHIP



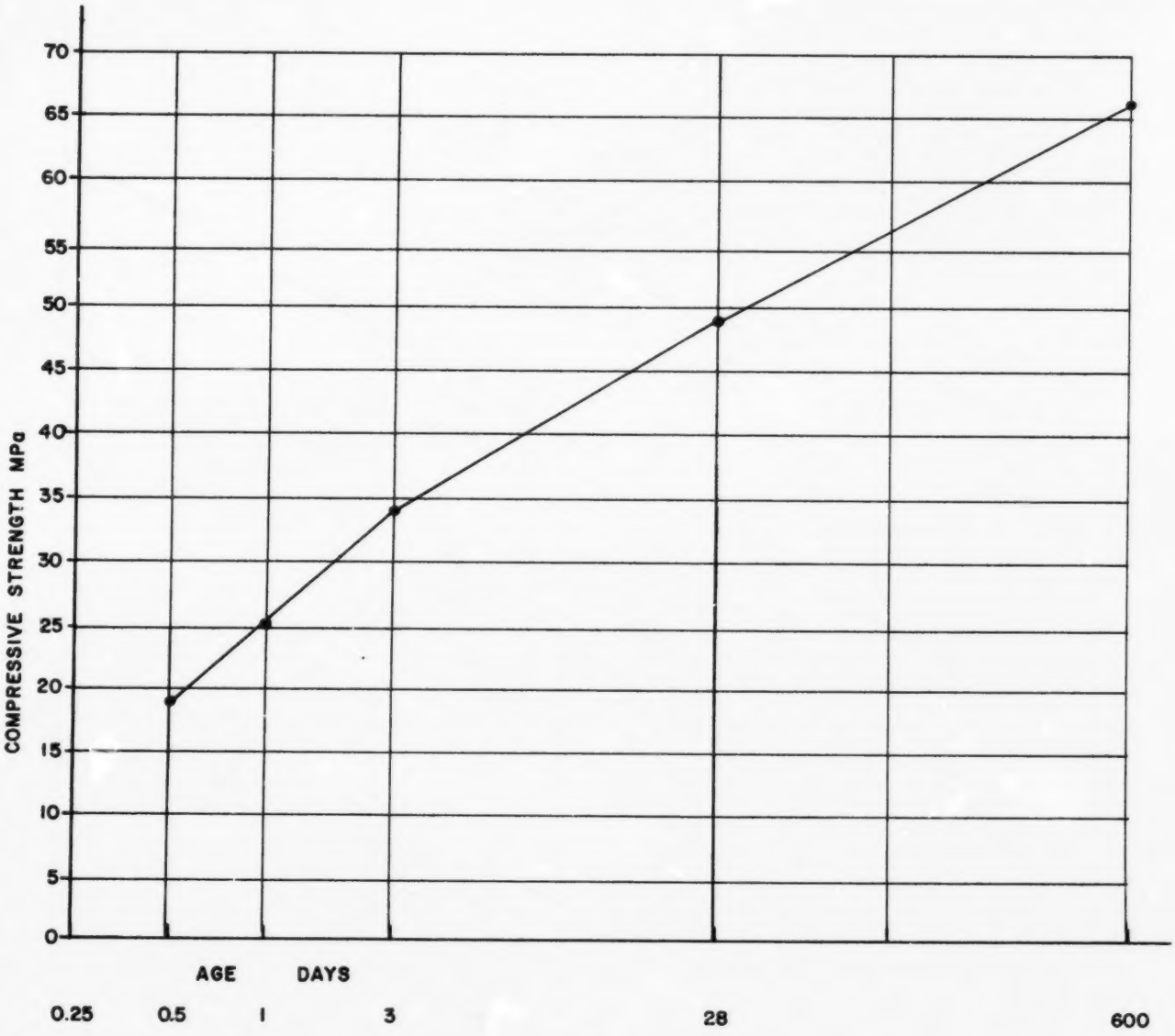


FIGURE 14-AGE STRENGTH RELATIONSHIP 41.4 MPa CLASS CONCRETE

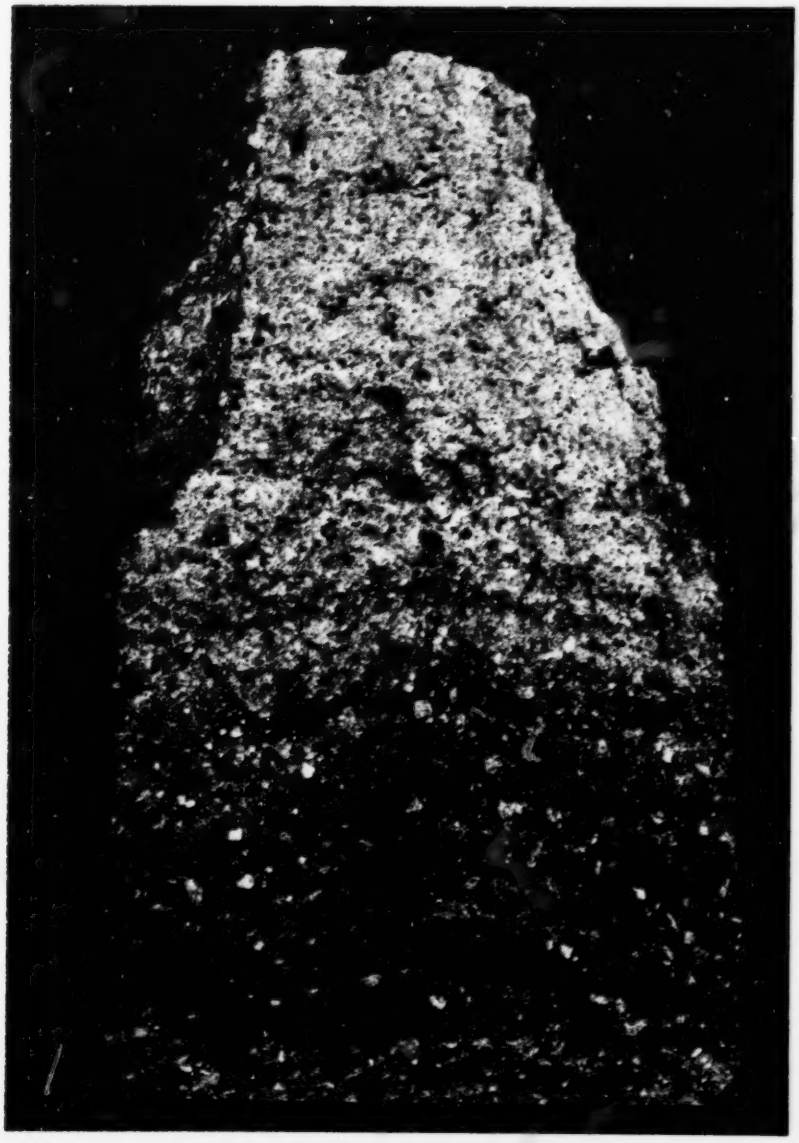


FIGURE 15

SEGREGATION IN WALL C-F

CORE No 66B

TABLE 1

Mix proportions proposed by the Ready Mix Supplier for the 41.4 MPa class concrete.

Concrete Segments - Contract 80-44
MIX DESIGN DATA

	DRY MASS kg/m^3
NORMAL PORTLAND CEMENT	465 kg
SAND MOYER	600 kg
STONE VINELAND 20mm	1165 kg
TOTAL WATER	150 kg
	2380 kg
ADMIXTURE MB 100 XR*	469 mL/100kg NPC
AIR ENTRAING AGENT NEUTRALIZED VINSOL RESIN** TO PROVIDE 5% $\pm$ 1% AIR CONTENT	
SPECIFIED SLUMP	60mm $\pm$ 20mm

* TYPE SR DESIGNATED MINIMUM DOSE 150 mL per 100 kg CEMENT PER MTC FORM 1303, DS:100.2

**MBAE 10

Tests on Segment 254 S.B. concrete on 23 10 81 indicated:

Air content	5.5%
Concrete Temperature	16^{o}C
Slump	75mm

Table 2
Compressive Strength and Density Data

Core No.	Location	$\frac{L}{D}$ Ratio	Compressive Strength MN/m^2 Mean	Compressive Strength MN/m^2 Std.Dev.	Density S.S.D. kg/m^3 Mean	Density S.S.D. kg/m^3 Std.Dev.
2	A-B	1.78	70.30		2432	
5	"	1.72	80.20		2412	
8	"	1.77	75.60		2386	
10	"	1.74	74.30		2429	
12	"	1.83	74.70		2384	
14B	"	1.62	61.30		2341	
			72.73	5.87	2397.0	31.40
17	B-C	1.75	68.70		2384	
18B	"	1.81	67.30		2378	
19	"	1.77	70.80		2393	
20	"	1.81	73.70		2383	
25D	"	1.85	68.86		2387	
27B	"	1.77	72.00		2389	
			70.23	2.17	2386.7	4.75
28B	C-D	2.00	64.76		2366	
30A	"	1.94	71.20		2377	
35	"	1.92	59.79		2367	
36	"	1.86	59.10		2372	
38	"	1.81	61.00		2367	
39	"	1.82	62.20		2391	
			63.00	4.09	2373.3	8.77
51A	B-E	1.96	64.00		2400	
52A	"	1.98	74.10		2396	
52B	"	1.97	66.90		2403	
53B	"	1.90	71.43		2392	
56B	"	1.97	65.54		2411	
57A	"	2.00	67.23		2415	
			68.20	3.48	2402.8	8.03
62B	C-F	2.00	66.60		2388	
68A	"	1.98	65.40		2378	
68B	"	2.00	70.28		2388	
70A	"	1.98	66.85		2362	
72A	"	1.95	65.06		2375	
73A	"	1.90	71.38		2403	
			67.60	2.39	2382.2	12.50
79	E-F	1.60	59.10		2388	
83	"	1.75	59.39		2384	
84	"	1.57	66.05		2385	
86	"	1.56	57.12		2372	
89	"	1.81	67.35		2400	
91	"	1.52	53.73		2373	
			60.46	4.80	2383.7	9.46
			Mean $\bar{X}$ 67.04		2387.5	
			Mean δ 5.78		18.12	

Table 3
Modulus of Elasticity Data

Core No.	Location	$E = \frac{GN}{m^2}$	$\bar{X}$	$\delta x.$
2	A-B	39.64		
5	"	35.44		
8	"	36.27		
10	"	34.82		
12	"	37.51		
14B	"	32.48		
			36.02	2.22
17	B-C	32.61		
18B	"	35.23		
19	"	34.75		
20	"	33.65		
25D	"	34.54		
27B	"	34.12		
			34.15	0.85
28B	C-D	31.92		
30A	"	34.13		
35	"	33.44		
36	"	32.29		
38	"	32.89		
39	"	33.44		
			33.02	0.75
51A	B-E	33.30		
52A	"	35.72		
52B	"	33.16		
53B	"	37.85		
56B	"	32.34		
57A	"	35.16		
			34.59	1.87
62B	C-F	33.51		
68A	"	33.65		
68B	"	33.92		
70A	"	32.68		
72A	"	32.54		
73A	"	34.47		
			33.46	0.67
79	E-F	29.03		
83	"	29.23		
84	"	31.92		
86	"	30.48		
89	"	34.61		
91	"	34.96		
			31.71	2.38
			$\bar{X}_{36}$ 33.83	δx_{36} 2.11

Table 4

Regression Analysis Data

No.	Location	"r" Factor	Explained Variable	a_o	a_1
A. - Modulus of Elasticity versus Compressive Strength					
1	A-B	0.371	119.613	37.426	0.98
2	B-C	0.253	8.489	92.368	-0.648
3	C-D	0.468	35.840	-21.780	2.568
4	B-E	0.766	34.486	18.945	1.424
5	C-F	0.803	16.172	-25.412	2.781
6	E-F	-0.274	48.057	51.241	0.291
7	GLOBAL	0.618	751.194	9.738	1.694
B. - Density versus Compressive Strength					
1	A-B	0.597	91.354	-195.527	0.112
2	B-C	0.388	7.416	-353.082	0.177
3	C-D	0.191	15.487	-149.065	0.089
4	B-E	-0.580	13.972	671.652	-0.251
5	C-F	0.718	12.509	-251.708	0.134
6	E-F	0.845	71.819	-971.913	0.433
7	GLOBAL	0.497	730.655	311.312	0.158
C. - Modulus of Elasticity versus Density					
1	A-B	0.611	11.665	-67.886	0.043
2	B-C	0.018	0.153	26.394	0.003
3	C-D	0.476	0.415	-63.150	0.041
4	B-E	-0.567	6.171	351.730	-0.132
5	C-F	0.881	0.906	-79.790	0.048
6	E-F	0.110	25.239	-34.349	0.028
7	GLOBAL	0.443	59.195	-89.013	0.051